INFLUENCE OF DIETARY ENERGY INTAKE DURING LACTATION AND
FOLLOWING WEANING ON SOW AND LITTER PERFORMANCE

by

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Introduction

In recent years the swine producer has catered to an industry (pork products) whose share of the market has plateaued and then declined under the pressures of increasing competition and changes in consumer demand. As competition for a finite market is increased, economic incentive for increased production efficiency is intensified. One factor crucial to increasing production efficiency is sow reproductive performance. Any improvement in ovulation rate, conception rate, farrowing interval, pig survival, or sow longevity may increase the efficiency of production. Modern management systems have decreased the age at which replacement gilts are placed into production, shortened the lactation period, changed body composition by decreasing subcutaneous reserves of fat, replaced seasonal production schemes with continuous farrowing schedules, and demanded that sows be rebred sooner after weaning. Composite demands placed on the sow by such intensive management systems may challenge the ability of the sow to maintain an adequate level of reproductive performance. Anestrus and infertility following the first lactation often are encountered. Research has shown that first-parity sows suffering heavy losses of backfat during lactation are more likely to have a delayed first estrus following weaning. Benefits of an energy

induced flush prior to breeding gilts are well documented. However, the effects of energy intake following the first lactation has not been fully examined. Thus, the objective of this review of literature is to examine the role of energy as it affects nutrition and reproduction in primiparous and multiparous sows. Efforts will be made to report and relate other crucial factors that ultimately may influence reproduction, including lactation performance, body composition, and endocrinological response to nutritional changes in primiparous sows.

Effect of feed intake on sow and litter performance

Feed intake during gestation. Elsley et al. (1969) observed that gains in sow weight during pregnancy were directly related to feed intake. Increasing feed intake during pregnancy (1.6, 2.4, or 3.2 kg/d) resulted in a linear increase in weight gain from mating through parturition. Weight gain during gestation was greatest in the first pregnancy and declined with succeeding pregnancies. A significant relationship between feed intake and net gestation gain was not found by Pathak and Ranjhan (1972), but only 16 sows completed their study.

Pond et al. (1983) found that less backfat was present by the sixteenth week of gestation in sows fed .6 kg/d than after 1.8 kg/d. They also found that increased free fatty acids (FFA) in plasma correlated with reduced backfat in gilts, apparently as a metabolic response to the calorie deficit. Ezekwe (1981) observed elevated concentrations of FFA in plasma in response to starvation of sows during late gestation. Likewise, Pond et al.

(1983) observed an increase in FFAs and decreased triglycerides when gestating gilts were restricted in feed intake. Elsley et al. (1969) reported consistent increases in birth weight of pigs when feed intake of the sow was increased during pregnancy. Lodge et al. (1966) observed reduced birth weights when gestating sows were fed 1.4 kg daily rather than 2.7 kg. Pond et al. (1983) demonstrated that the effect of feed restriction during gestation on birth weight of pigs was dependent upon the genetic propensity of the gilt to be obese. In their study, pig birth weight was reduced when gestation energy intake of obese sows was restricted but had no effect on the birth weights of contemporary or lean sows. These researchers noted that the survival rate of pigs from obese dams was higher than from lean dams.

High levels of feed intake throughout pregnancy has been associated with increased weaning weight of litters. In the second and third parities, Elsley et al. (1969) attributed the heavier weaning weights to increased birth weights. Pond et al. (1983) restricted feed intake during gestation for gilts in average body condition and also decreased preweaning growth of pigs. Although they were unable to determine whether poor growth of pigs was due to reduced milk yield or to a carry-over effect of poor prenatal growth, they suggested the former is probable and noted that energy restriction during gestation has been shown to reduce mammary tissue development in rats.

Effects of gestation feed intake on reproductive performance are uncertain. Lodge et al. (1966) reported no effect on

reproduction or litter size when feed intake was varied between 1.4 and 2.7 kg/d. This is in contrast to Elsley et al. (1969) who found that increasing feed intake above 1.6 kg tended to reduce the number of pigs born in the first litter. In the latter study, the most dramatic reduction in litter size (9.9 vs 10.8) occurred when sows were fed 3.2 kg daily during their first gestation as compared to 1.6 kg/d. No effects on litter size were reported in later parities. Therefore, the optimum intake during the first gestation to maximize reproductive performance, appears to be somewhere in the broad range between 1.4 and 3.2 kg/d. Because of variation in diet composition and the possibility of confounding nutrient effects, the need remains to examine individual components of the sow's diet to identify the specific nutrients affecting sow productivity.

Feed intake during lactation. Weight loss of sows during lactation can be minimized by feeding a high daily intake. Loss of weight during lactation is dependent on sow feed intake while lactating (King and Williams, 1984a; Elsley et al., 1969) and gains in sow weight during the previous pregnancy (Elsley et al., 1969), such that losses are reduced when sows are fed additional feed during lactation but increased with increasing weight gain during gestation. Likewise, weight loss has been shown to increase when sows are restricted in feed intake during the last week of lactation (Brooks and Cole, 1973). King and Williams (1984a) also have shown that reducing daily feed consumption of lactating sows from ad libitum to 2.0 kg/d resulted in more backfat lost by weaning. The evidence strongly

suggests that feeding level during lactation has no influence on ovulation rate, embryo survival, number of pigs born per litter or birth weight of pigs in the subsequent parity (King and Williams, 1984a) and additional intake only slightly increases growth rate of pigs to weaning (Elsley et al., 1969). However, in these studies pigs were given access to creep feed during lactation and that may have masked increased milk production (as measured by weaning weights).

King and Williams (1984a) found a relationship between feed intake during lactation and the number of days to estrus following weaning. They concluded that estrus after weaning is delayed in first-litter sows when considerable amounts of backfat and weight are lost as a result of low feed intake during lactation. More sows fed ad libitum during lactation exhibited estrus (78 vs 38%) and ovulated (90 vs 40%) by 8 d after weaning than sows with restricted (2.0 kg/d) feed intake throughout lactation.

Elsley et al. (1969) studied the efficacy of three levels of feed intake during gestation, followed by two levels during lactation through three parities. They concluded that only when feeding levels during pregnancy are low (1.6 kg/d) is feed consumption during lactation above 2.3 kg (plus .2 kg/suckled pig) required to minimize the amount of sow feed/kg of pig produced at weaning.

Feed intake between weaning and mating. Few experiments have examined the effects of feed intake following the first lactation. King and Williams (1984a) reported that additional

feed intake between weaning and mating increased sow weight and backfat gain during the subsequent gestation period. In addition, these researchers demonstrated a flushing effect when primiparous sows were fed 4 kg/d compared with 1.5 kg/d between weaning and mating. The flush resulted in higher ovulation rates (14.8 vs 13.0) and tended to increase subsequent litter size. When multiparous sows were fed 1.8 to 4.8 kg daily from weaning to remating, Brooks et al. (1975) observed no differences in conception rate, interval from weaning to remating, or subsequent litter size. Previous research by Cole and Brooks (1973) demonstrated a linear decrease in the interval from weaning to remating, and in the number of anestrous primiparous sows as daily feed intake increased (1.8, 2.7, or 3.6 kg/d) between weaning and remating. A second study using third parity sows failed to show a reproductive response to increasing feed intake between weaning and remating. Likewise, level of postweaning feed intake following 24 h of starvation at weaning has shown no effect on reproductive performance (Etienne et al., 1976). Trajkovic et al. (1980) concluded that primiparous sows and sows in poor condition require abundant feed from weaning until estrus.

A determination of the dietary feed intake necessary to maintain a high level of sow productivity is worthy of research. However, with the tremendous variation in diet composition and quality of ingredients, a wide range of feed intake recommendations should come as no surprise. Furthermore, it should be recognized that the possible effects of individual

nutrients have not been studied thoroughly and that a single nutritional component of sow diets, or a combination of nutritional factors, may be responsible for many of the results obtained by changing feed intake during gestation, lactation, or following weaning. Therefore, it is necessary to review the effects of certain nutritional factors that may explain the results observed when feed intake is varied.

Effect of protein intake on sow and litter performance

Protein intake during gestation. Adequate protein intake is essential to maximize sow productivity. Failing to supply sufficient dietary protein may increase the catabolic demand on reserves in nitrogenous tissue. Protein needs of first–litter sows may be more critical than in later parities because of added requirements to maintain adequate milk production and continued body growth.

Sows fed a high daily intake of crude protein (CP; 295 or 309 g/d, respectively) during gestation are known to gain more weight by parturition than those fed 9 g/d (Pond et al., 1968) or 45 g/d (DeGeeter et al., 1972). Frobish et al. (1978) observed a tendency for weight gain during gestation to be reduced with successive parities. Baker et al. (1970) reported that gravid gilts fed a fortified corn diet gained less weight than those fed 12, 16, or 20% CP. Mahan and Mangan (1975) reported that gilts fed a 13 or 17% CP diet during pregnancy gained more weight (42 vs 33 kg) than those fed a 9% CP diet. Results reported by Greenhalgh et al. (1977) also showed no additional response in

weight gain to dietary protein levels above 13.5% (270 g/d) during the first pregnancy. However, their research indicated that sows fed additional protein had increased weight gains during pregnancy, but also increased weight loss in the following lactation. Thus, overall weight change in each parity was not affected by protein intake during gestation.

Protein intake during pregnancy is associated with the quantity of nitrogen retained by gravid sows. Miller et al. (1969) found that at least 285 g/d of crude protein (CP) were required to maximize nitrogen retention at d 100 of gestation. These findings have further defined the role and limitations of protein for growth and development of the gestating gilt. However, such factors are of little value if they do not affect sow productivity or litter performance. DeGeeter et al. (1972) reported no adverse effects on litter size or birth weight after severe protein restriction (2% CP) in gravid gilts. These results have been verified by others with less severe restriction (Mahan and Mangan, 1975). In contrast, Frobish et al. (1978) observed a tendency for multiparous sows fed 9% protein during gestation to farrow fewer pigs (P<.05) per litter than those fed 15% CP. Similar results were observed in first and third parity sows by Greenhalgh et al. (1977).

DeGeeter et al. (1972) examined the effects of gestation diets containing 2% (LP) or 17% (HP) protein on progeny performance. At birth one-half of the pigs were cross-fostered to mothers on opposite gestation treatments. They observed a significant growth depression (159 vs 207 g/d) for pigs that suckled primiparous

sows fed a LP diet compared with the HP gestation diet. These authors concluded that the level of protein fed during gestation markedly affected milk production of lactating sows when measured by gain of pigs. They also provided evidence that low protein intake during gestation may have a stunting effect on progeny growth. More recently, Frobish et al. (1978) indicated that both the content of protein and fat of sow's milk are increased when dietary protein concentrations are increased from 9 to 15% during gestation.

Mahan and Mangan (1975) fed three levels of CP during gestation (9, 13 or 17%) and two during lactation (12 or 18%) to evaluate carry-over effects of maternal tissue reserves from gestation on subsequent milk production (measured by litter gain). Weaning weight responded to increasing protein intake during gestation and depended on the level of protein fed during lactation. Their results demonstrate that the growth depression characteristic of pigs nursing sows fed inadequate quantities of protein during gestation may be overcome by feeding more protein during lactation. Mahan and Mangan (1975) concluded that if adequate or surplus amino acids are supplied in the lactation diet, previous status of tissue reserve does not affect litter performance. Frobish et al. (1978) reported a decrease in pig birth weight associated with increasing lactation protein intake in litters nursing sows restricted in CP during gestation.

Haye et al. (1981) reported a lower concentration of immunoglobulin in serum of pigs when sows were fed a 9/18% CP gestation/lactation protein sequence in the first parity, but no

immunoglobulin suppression was observed when the protein sequence was repeated in later parities. Thus, restricting protein during gestation may influence colostral concentrations of immunoglobulin during the first parity.

The relationship of nitrogen retention to fetal development is unclear. Jones and Maxwell (1974) reported that feeding additional dietary protein to gilts prior to mating increased early pregnancy nitrogen retention, and number of corpora lutea at 30 d, but had no effect on embryonic growth or number of live embryoes.

Mahan and Mangan (1975) suggested a priority system for the use of dietary amino acids for gestating sows. Initial use (of amino acids) is for the formation of those proteins essential for life processes (maintenance), with reproduction and body tissue growth each of a lower priority, respectively.

Protein intake during lactation. Lactational protein intake influences postpartum weight loss. Greenhalgh et al. (1977) reported that primiparous sows fed 17% CP during a 42-day lactation lost less weight (8.7 vs 2.7 kg) postpartum than sows fed a 13% CP diet. Similar observations were made by DeGeeter et al. (1972) when diets containing 5% or 17% protein were fed. DeGeeter et al. (1972) reported interactive effects of gestation and lactation protein intake on postpartum changes in body weight as the lactational weight loss by sows fed low protein during lactation was further increased by low protein during gestation. Mahan and Mangan (1975) provided evidence that sow feed intake during lactation, and litter gain was affected by

interactive effects of gestational and lactational protein intake. O'Grady and Hanrahan (1975) reported that weight loss was minimized by feeding a diet containing 11.8% CP, .78% lysine and .5% sulfur-containing amino acids. However, litter and pig weight did not respond to lactation diets having more than 9.3% crude protein, .58% lysine and .39% sulfur-containing amino acids. O'Grady and Hanrahan (1975) concluded that protein and amino acid levels necessary to minimize loss of weight during lactation are considerably higher than those necessary to maximize milk yield and litter gain.

Sohail et al. (1974) reported that dietary lysine above .97% (38.4 g/d) probably exceeded the requirement in the lactating sow based on concentrations of lysine in plasma and urea in serum. However, recommendations based on urea in serum would probably reflect the requirements to minimize lactational weight loss and may have little bearing on the requirements to maximize milk production. Based on milk output from sows fed tryptophan-supplemented barley diets, McDougall and Fowler (1974) suggested that total lysine requirements did not exceed 4.8 % of dietary protein. Mahan and Grifo (1975) reported a linear increase in daily feed intake during lactation and sow weight at weaning with increasing dietary concentrations of protein (12, 14, 16 or 18% CP) during lactation from sows fed only a fortified corn basal diet during the prior gestation. Litter gains, pig weaning weights and concentrations of protein in milk were linearly increased with increasing postpartum protein intake.

protein diet during lactation consumed less feed than those fed 18% CP. However, they also reported that sows fed the lactation diet lower in protein (12%) had increased feed intake following a high protein intake (17%) during gestation. Thus, these authors have demonstrated that limiting dietary protein intake during gestation can affect the level of ad libitum intake consumed during the following lactation. These data may suggest that endogenous protein reserves accumulated during gestation can be utilized to offset inhibitory effects of limited lactational protein on voluntary feed intake.

DeGeeter et al. (1972) found reduced preweaning daily gain by pigs whose dams were fed 5% CP compared with a 17% CP lactational diet. Pig survival was unaffected by dietary protein in the first trial. However, in a second trial in the presence of an outbreak of enteritis, pig survival was subsequently reduced in litters nursing dams fed the low protein diet during gestation or lactation. Conversely, MacPherson et al. (1969) reported a linear increase in pig weight gain as protein in the diet decreased (19, 16.5 or 14.0% CP) in the first lactation. When the effect of protein levels of gestation and lactation was examined over three parities, Frobish et al. (1978) reported a decrease in birth weight and an increased 14-d weight of pigs nursing sows fed increasing protein (12, 16, or 20%) during lactation. This is in contrast to findings by MacPherson et al. (1969) that protein concentration fed during lactation has no effect on number or weight of pigs at birth.

Chen et al. (1978) observed an increase in pig gain and sow milk yield with progressively increasing dietary lysine (up to .59%) in a 10% protein basal lactation diet. Milk fat content increased linearly in the first parity in response to increasing dietary lysine but milk lactose and protein levels were unaffected.

Little research has been conducted to evaluate the effects of dietary protein intake during gestation or lactation on sow longevity, or upon the interval from weaning to fertile mating. Greenhalgh et al. (1974) reported that the interval from weaning to mating was unaffected by levels of protein ranging from 9 to 15% during gestation when sows were fed either 13 or 17% protein during lactation.

The National Research Council (1979) has given minimum recommendations of 216 g/d of crude protein from a 12% protein diet during gestation and 618 g of crude protein from a 13% protein diet for moderately producing sows during lactation. These recommendations may be met by feeding 1.8 kg of a gestation diet and 4.75 kg of a lactation diet daily.

Influence of dietary energy on sow and litter performance

Energy intake during lactation. Usually dietary energy effects are evaluated by considering the response to two or more isonitrogenous diets differing only in energy value as a result of starch (or fat) addition. Accumulative evidence provided by Nelssen et al., 1985a; O'Grady et al., 1975; Reese et al., 1982a,b, 1984 suggests that the quantity of weight lost by

lactating sows is largely dependent upon average daily energy intake during lactation. In agreement, Reese et al. (1982a) observed that both first and second parity sows consuming 8 Mcal of metabolizable energy (ME) lost more weight and backfat during lactation than sows fed 16 Mcal/d. Although unable to determine the composition of the weight loss, Reese et al. (1982a) suggested that the substantial loss of backfat indicates that adipose tissue probably accounts for a major portion of the weight lost when energy intake is restricted. Reese et al. (1982b) observed that primiparous sows fed 8 Mcal/d during lactation gained more weight and deposited more backfat during the following gestation. These authors concluded that primiparous sows fed low energy during lactation apparently compensated for their greater weight and backfat loss. Reese et al. (1982b) noted that the degree of weight gain during the following gestation may be dependent upon the degree of dietary restriction imposed during lactation. Despite compensitory effects, sows restricted in energy intake during the first lactation weighed less and had less backfat following the second parturition.

The association between dietary energy intake during lactation and litter performance has been examined by several researchers. O'Grady et al. (1973) found no effect on litter or pig weaning weights when first and second parity sows were provided diets ranging from 12.2 to 19.6 Mcal of digestible energy (DE) daily. Reese et al. (1982a,b; 1984) were inconsistent in showing a reduction in pig weaning weight for both first and second parity sows when dietary energy intake of the sow was

restricted during lactation. With a narrower range of energy intakes during lactation, Nelssen et al. (1985a) reported a linear increase in pig weight on d 14 of lactation, and observed that both pig and litter weaning weights increased with increasing sow energy intake. The failure to observe a weaning weight response to fluctuations in energy intake prior to research published by Reese et al. (1982a) is likely due to access to a creep feed during lactation which may have masked any effects on milk production.

Effects of energy intake on pig performance has been attributed to changes in milk yield and (or) composition. Milk composition is not greatly affected by energy intake in the first three lactations (O'Grady et al., 1973). However, a linear increase in milk yield was observed in the second and third lactations with increasing dietary energy intake. Likewise, the apparent gross efficiency of protein utilization for milk production increased with increasing energy intake in the second and third lactations, but no increase was observed in the first parity. The authors concluded that energy was the factor limiting milk production in the second and third parities when less than 16.1 Mcal of DE was fed to a sow nursing 9 pigs. Also, they observed that gilts are able to continue producing milk while losing weight. It has been reported that the apparent gross energetic efficency of milk secretion is reduced with increasing energy intake, and that this reduction is most dramatic in the first parity (O'Grady et al., 1973). These data seem consistent with the idea that the large weight loss observed in first parity

sows probably is the result of utilization of body tissue reserves to supply nutrients for milk production.

A decrease in apparent energetic efficiency of milk production with increasing energy intake suggests that tissue catabolism provides a portion of the energy needs for milk production when dietary energy is restricted. Using blood urea nitrogen concentration, Reese et al. (1982a) provided evidence in primiparous sows that amino acid catabolism during the first 14 d of lactation is reduced when energy intake is increased from 8 to 16 Mcal/d. However, no further increase in amino acid catabolism was observed between 14 and 26 d of lactation when sows were fed daily energy intakes throughout lactation of at least 12 Mcal/d.

Blood urea nitrogen concentrations do not suggest the origin (dietary vs. endogenous) of amino acids. However, the concentration of creatinine in serum increases with progressive muscle degradation (Wallash, 1978). Thus serum creatinine concentration has been used to determine the origin of amino acids which have been deaminated for use as an energetic substrate. Based on serum creatinine concentration, Reese et al. (1984) observed a tendency for first-parity sows restricted in energy intake to 8 Mcal/d to have more muscle wasting at the time of weaning than sows fed 16 Mcal/d. Nelssen et al. (1985a) found no difference in serum creatinine concentrations for sows fed 10, 12 or 14 Mcal/d.

As our knowledge of the role of dietary energy as a substrate for maintenance of body tissues and milk production

continues to evolve, so then has our curiosity intensified as to the effect of caloric intake on reproduction. O'Grady et al. (1973) studied the effects of various energy intakes during lactation on subsequent reproductive performance. They reported a linear reduction in the number of pigs born in the second parity with increasing energy intake in the previous lactation. However, sows fed low energy during the first two parities farrowed lighter pigs in the third parity. Yet, energy intake had no effect on the interval between weaning and effective mating. Reese et al. (1982a) found that fewer primiparous sows exhibited estrus within 7, 14, 21 and 70 d postweaning when fed 8 Mcal ME as compared to energy consumptions of 12 or 16 Mcal/d. Also, fewer second parity sows restricted in energy intake exhibited estrus within 7 d postweaning (Reese et al. 1982a,b). Reese et al. (1984) found that 51% fewer primiparous sows restricted to 8 Mcal/d during lactation exhibited estrus by 14 d postweaning than those fed 16 Mcal daily. Likewise, sows that have the largest weight and backfat losses have been shown to have the highest incidence of anestrus (Reese et al., 1982a). However, with less severe energy restriction (10, 12 or 14 Mcal ME/d), Nelssen et al. (1985a) observed no significant delay in the interval from weaning to estrus in primiparous sows. Therefore, the degree of energy restriction may be a critical factor limiting normal reproductive function in the primiparous sow. Nelssen et al. (1985a) concluded that the National Research Council (1979) recommendations of 12.8 Mcal/d is adequate for primiparous sows retained through one parity. The caloric intake suggested by the

National Research Council (1979) of 12.8 Mcal/d may often exceed the level of ad libitum consumption. Cox et al. (1983) reported that primiparous sows consumed only 8.9 Mcal/d of a corn/soybean meal diet compared to 9.6 Mcal/d of a diet containing 10% added fat during lactation. Attempts to increase energy intake by feeding a high fat diet may result in reduced energy digestibility of the diet. Nelssen et al. (1985b) reported that when fat was included as a primary energy source in the lactation diet, energy digestibility was lower than for starch based diets. Thus, it appears that the energy needs of the primiparous sow necessary to maintain adequate body weight and reproductive function are not always met.

Effects of protein-energy combinations during lactation

Although numerous researchers have examined independently the effects of protein and energy intake on sow and litter performance, only two research trials have considered possible interactive effects of dietary energy and protein. Both trials were conducted with first-parity lactating sows. King and Williams (1984b) found that weight loss during lactation was reduced (32.5 vs 3.9 kg, respectively) in sows fed approximately 13.5 Mcal DE/d (HE) after the CP intake was increased from 302 (LP) to 745 g/d (HP). Thus, they concluded that when sows were fed a high energy diet, increased protein intake markedly reduced live-weight loss. However, little backfat loss was evident in sows fed HE regardless of protein intake. In contrast, sows fed approximately 6.3 Mcal DE/d (LE) had substantial weight and backfat loss during lactation. Backfat loss was found to be more

pronounced among sows fed HP diets. Thus, an interaction
between energy intake and protein intake for live weight and
backfat loss was reported.

King and Williams (1984b) suggested that increasing protein
intake for sows fed a low energy diet is likely to increase
urinary energy loss and may account for the high backfat loss
observed in sows fed LE/HP. Positive nitrogen balance was
observed only for sows receiving high levels of both energy and
protein. Based on estimated milk yield (Agricultural Research
Council, 1981), King and Williams (1984b) reported that daily
nitrogen output in milk was higher from sows that receive LE/HP
than from sows fed other energy/protein combinations. Brendemuhl
(1985) reported that sows fed LP (380 g/d) or LE (8 Mcal/d) lost
more weight during lactation than sows fed either HP (760 g/d)
or HE (16 Mcal/d). Additionally, they found that sow weight
loss decreased in response to increased energy intake to a
greater extent when protein was high. Backfat loss was reported
to be increased as a result of energy restriction and when
dietary protein intake was increased. Brendemuhl (1985)
concluded that tissue catabolism occurs as a result of both
energy and protein restriction. They suggested however, that
despite similarities in weight loss between sows fed HE/LP and
those fed LE/HP, the composition of the loss could be different.

Brendemuhl (1985) evaluated the litter weaning weights for
sows fed different energy/protein combinations. Pigs suckling
sows fed high amounts of either energy or protein were heavier
at weaning. Litter weaning weights were highest when sows were

fed HP but were not influenced by energy intake. Although a trend towards heavier litters from sows fed the HE diets was observed, it was negated by the fact that sows fed HP/LE weaned pigs nearly as heavy (6.5 vs 6.8 kg) as those fed HP/HE. Based on poor litter weaning weights from sows fed HE/LP, these researchers suggested that the combination of LP with HE possibly restricts the amount of protein available for metabolic functions even more than the LE–LP combination, because of the increased need for protein to utilize the increased energy substrates. However, no mechanism supporting this hypothesis was proposed.

Brendemuhl (1985) examined the effect of energy and(or) protein restriction on concentrations of urea in serum during lactation. They reported a protein by energy interaction such that serum urea increased in response to protein to a greater extent when energy content of the diet was low. Also, serum urea concentration was higher in sows fed LE than HE, and HP than LP, respectively. Based on serum urea concentrations this research indicated that sows restricted in protein and(or) energy can utilize protein as an energy substrate. Also, they have demonstrated that restriction of protein and(or) energy can adversely affect sow and litter performance.

An ultimate consideration when proposing any dietary change to affect the nutritional status of primiparous sows is to determine the net effect that the proposed adjustment may have on future reproductive function. In accordance, King and Williams (1984b) reported that ovulation rate, embryonic

mortality, and subsequent litter size were unaffected by energy or protein intake. However, more sows fed HE/HP (14.2 Mcal DE/745 g CP, daily) exhibited estrus (88 vs 53%) than sows restricted in energy and(or) protein intake. Brendemuhl (1985) reported that a higher percentage of sows fed the HP diet were detected in estrus by d 7, 14, and 35 postweaning. King and Williams (1984b) concluded that when lactating sows lost appreciable amounts of live weight (30 to 35 kg) and were in a negative nitrogen balance due to restricted protein and(or) energy intake, estrus was delayed after weaning.

Energy intake and endocrine status

A number of researchers have attributed changes in reproductive performance, especially the interval to estrus after weaning, to the level of dietary energy consumption. However, little research has been conducted to study the effects of dietary energy on the profile of hormones thought to regulate reproduction. In two seperate studies, Nelssen (1983) induced nutritional anestrus in first-parity sows by restricting feed intake to 8 or 10 Mcal/d during lactation. The combined results of these studies show that 14, 50, 100, 100 and 100% of those sows fed 8, 10, 12, 14, or 16 Mcal/d, respectively, exhibited estrus within 7 d after weaning. To account for an increased incidence of anestrus when energy intake was restricted, serum concentrations of estradiol (E_2), luteinizing hormone (LH), progesterone (P_4), triodothyronine (T_3) and thyroxine (T_4) were reported. Mean LH concentrations at weaning were similar between sows fed 8 (LE) or 16 (HE) Mcal/d. However, by 6 d

postweaning the serum concentration of LH for sows fed HE was higher than those fed LE. Likewise, the frequency of LH pulses was increased on d 3 postweaning in sows fed 16 Mcal/d. Nelssen (1983) reported similar LH concentrations from d 1 to d 5 postweaning between sows fed 12 or 14 Mcal/d although peak concentrations were observed on d 4 and 5, respectively. Anestrus sows had near baseline concentrations of LH during d 1 to 6 following weaning. Sows fed 10 Mcal/d that exhibited estrus, had a lower peak concentration of LH than sows fed at least 12 Mcal/d. Nelssen (1983) suggested that nutritionally induced anestrus may be due to a failure to release sufficient gonadotrophins to initiate estrus following weaning.

Nelssen (1983) reported that sows fed 16 Mcal/d have higher concentrations of estradiol (E_2) on d 3 to 6 following weaning than those restricted to 8 Mcal/d. Sows that consumed 12 or 14 Mcal/d had a higher concentration of E_2 in serum on d 1 to 4 postweaning than those fed only 10 Mcal/d of E_2 in serum. Furthermore, sows fed 10 Mcal ME that failed to return to estrus had lower concentrations of E_2 on d 2 or 4 than sows fed at least 12 Mcal/d. The author suggested that sows restricted in energy, synthesize and secrete insufficient E_2 to trigger an LH surge. Reasons for differing hormonal and estrus response to dietary energy restriction are unknown. Postweaning serum progesterone concentrations of sows exhibiting estrus by d 6 after weaning were not found to be directly affected by energy intake (Nelssen, 1983).

Reese (1983) has suggested that nutritionally induced anestrus sows are hyperthyroid. To test this hypothesis, Nelssen (1983) measured serum T_3 and T_4 concentrations following weaning in primiparous sows. At weaning sows fed LE (8 Mcal/d) and which failed to return to estrus postweaning had lower T_3 and T_4 concentrations than those fed HE (16 Mcal/d). Sows restricted in energy intake that returned to estrus within 6 d after weaning had the highest T_3 and T_4 concentrations on d 1, 2 and 3 postweaning, respectively. Similar observations were reported by Nelssen (1983) when serum T_3 and T_4 concentrations were highest on d 1 and(or) d 2 postweaning in those sows fed 10 compared to 12 or 14 Mcal/d that returned to estrus within 6 d postweaning. In contrast, T_3 and T_4 concentrations on d 5 and 6 postweaning tended to be lower in anestrus sows fed 10 Mcal/d. Thus, the author failed to confirm that a hyperthyroid condition is associated with nutritionally induced anestrus. However, he observed that sows restricted in energy intake during lactation and that remain anestrus following weaning, appear to develop a hypothyroid condition concomitant with the time of behavioral estrus in sows fed adequate energy.

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Introduction

In most U.S. Swine operations first-parity sows account for a sizable percentage of all reproducing females. Primiparous sows often limit a herd's reproductive efficiency and litter performance. A high incidence of anestrus following weaning of a sow's first litter is frequently encountered. King and Williams (1984a) demonstrated that restriction of feed intake during lactation reduced the percentage of primiparous sows exhibiting estrus and ovulating within 8 d after weaning. An increase in the incidence of anestrus also has been reported when energy intake of primiparous sows is restricted to 8 as compared to 12 or 16 Mcal/d during lactation (Reese et al., 1982a, 1984). Nelssen et al. (1985a) found no major effect of interval to estrus when lactating primiparous sows were fed 10, 12, or 14 Mcal/d, but sows fed 10 Mcal/d required slightly longer to return to estrus. Reese et al. (1982a,b) reported that anestrus was most prevalent among sows having the largest weight and backfat losses during lactation. Reese et al. (1984) provided evidence that excess catabolism of body fat during lactation may be the factor limiting the occurrence of estrus after the first litter is weaned.

In first, second and third parity sows, Tribble and Orr (1982) have observed little or no reproductive advantage for increasing feed intake from 1.8 to 3.6 kg for 6 d after weaning. However, the possibility of supplying additional energy after weaning to overcome the adverse effects of large weight and backfat losses during the first lactation has not been studied.

Likewise, little information is available on the effects of lactation and postweaning energy intake maintained through the first two parities. Due to its economic impact, insights into the relationship between body tissue reserves of sows and reproductive performance may be expected to provide information of direct application to swine production. Therefore, the primary objectives of the present study were to: (1) determine the effects of providing additional energy after weaning to primiparous sows whose energy intake had been limited during lactation; and (2) evaluate the cumulative effects, through two parities, of energy intake during lactation and from weaning to estrus. Sow's body weight, backfat, serum creatinine and urea, estrous and litter performance were measured to evaluate treatment effects.

Experimental Procedure

General. One hundred-four Duroc x Yorkshire primiparous sows (four replicates), were fed daily 1.82 kg of a grain-soybean meal diet containing 14% crude protein (table 1) during gestation. Replications were distributed across season and each trial continued through the first and second parity. Sows were moved from outside gestation lots to farrowing crates in an environmentally controlled building on d 108 of gestation and fed daily 2.27 kg of the 8 Mcal lactation diet (table 1). At parturition, sows were assigned randomly to dietary treatments calculated to provide a daily intake of 8 or 16 Mcal of metablizable energy (ME) during a 21-d lactation. Daily allowances of protein, vitamins, and minerals were the same for all sows and met or exceeded the recommendations of the National Research Council (1979). Energy intake was adjusted by adding wheat starch, dried fat, and tallow. During lactation, each diet provided 24 percent of the daily energy intake from a fat source. Feed not consumed was weighed and recorded weekly.

Pigs were processed and weighed and litter size was equalized within a block of two sows receiving different lactation treatments within 24 h after parturition. Pigs were not given creep feed, but could consume sow feed. Weights and death losses of pigs were recorded on d 1, 14 and 21 of lactation.

Sows were weighed and depth of backfat was determined by ultrasound[1] adjacent to the first and 13th ribs and the last

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[1]Scanoprobe, IthaCo Inc., Ithaca, NY 14850.

lumbar vertebra on d 108 of gestation and backfat measurements were then averaged. Blood was collected from the anterior vena cava of each sow between 3 and 4 h after the morning feeding (0800h), immediately placed on ice, refrigerated at 5 C until serum was harvested by centrifugation, and then frozen (-20 C). Backfat thickness and weight of sows were recorded and additional blood was collected on d 14 and 21 of lactation and on d 14 and 28 after weaning.

Sows were moved to an environmentally controlled building at weaning and placed in gestation stalls (.5 x 1.7m). Sows were cooled by a drip sprinkling system (Nichols et al., 1983) activated at 29 C during summer months. During winter months, temperature was regulated to no less than 18 C. Sows were assigned randomly within each lactation treatment to diets providing 5.75 or 11.5 Mcal/d (table 1). Postweaning diets continued until estrus and then sows were fed 1.82 $kg \cdot sow^{-1} \cdot d^{-1}$ of the gestation diet (table 1). Sows were checked for estrus twice daily (0830 and 1600h) in the presence of a boar beginning on d 3 after weaning and were considered in estrus when they stood in response to back pressure or mounting by the boar. Gilts were first inseminated artifically or mated 8 to 16 h after the onset of estrus, whereas sows were inseminated or mated 24 h after detecting estrus and both gilts and sows were remated or reinseminated 8 to 16 h after their initial service. Estrous detection continued until estrus or for a maximum of 30 d after weaning. Blood samples were collected weekly from sows not exhibiting estrus within 15 d after weaning and progesterone in

serum was determined (Davis et al., 1985). Progesterone concentrations >2 ng/ml were considered indicative of ovulation 4 to 16 d earlier. Any sow not detected in estrus within 30 d after weaning was slaughtered and her ovaries examined for luteal tissue and corpora albacantia. Sows showing evidence of ovarian function as determined by progesterone concentrations or ovarian examination were considered to have either ovulated without exhibiting estrus or to have not been detected in estrus. Estrous sows were tested for pregnancy 30 to 40 d after service and pregnant sows were transfered to outside lots and fed individually until d 108 of gestation. The same lactation and postweaning dietary treatments were used during the first and second parity. Animal care and data collection for parity 2 were the same as described for parity 1. Estrus detection was continued for a maximum of 30 d after the second lactation.

Serum urea nitrogen concentration was determined by a modification[2] of the automated procedures described by Marsh et al. (1965). Serum creatinine concentrations also were determined by automated[3] procedures described by Chasson et al. (1961). Samples of each diet were analyzed[4] to determine crude protein,

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[2,3]Technicon Instruments Corp., Industrial method # 339-01 for urea nitrogen determination, Technicon method # SE4-0011FH4 for creatinine determination, Tarrytown, NY 10591.

[4]Woodson-Tenent Laboratories, Des Moines, IA 50305.

ether extract, nitrogen-free extract, moisture, ash, calcium, and phosphorus. Gross energy value of each diet was determined by bomb calorimetry.

Statistical Analyses. Effects of energy intake on sow and litter performance were determined by least-squares analyses of covariance (SAS, 1982). The statistical model was a split-plot in time with sow (whole plot) and time of measurement as the subplot. Covariates for analyses of sow performance were backfat on d 108 of gestation, sow weight and number of pigs on d 1 postpartum and age of pigs when weighed. Analyses of litter performance included age of pigs when weighed and number of pigs on d 1 of lactation. Number of pigs born alive in the first parity was included as a covariate for testing the effects of first parity dietary treatments on subsequent littersize. Treatment effects on the percentage of sows exhibiting estrus by 7, 14, 21 and 28 d after weaning were tested as catagorical data using procedure FUNCAT of the Statistical Analysis System (SAS, 1982).

Results

Changes in backfat and body weight for sows in response to 8 and 16 Mcal/d during the first lactation are summarized in table 2. Gains of sow weight and backfat during the first gestation, and weight and backfat on d 108 of gestation were similar for sows in each lactation treatment. Regardless of lactational treatment, sows lost weight and backfat during lactation. However, primiparous sows fed 16 Mcal/d during lactation lost less (P<.01) weight and backfat than those fed 8 Mcal/d. Consequently, sows fed 8 Mcal/d during lactation weighed less (P<.01) and had less (P<.01) backfat at the time of weaning than sows fed 16 Mcal/d (table 4).

Effects of energy intake during lactation on changes of weight and backfat for second-parity sows are shown in table 3. As for primiparous sows, second-parity sows fed 8 Mcal/d lost more (P<.01) weight during lactation than sows fed 16 Mcal/d. During the second lactation, sows fed 16 Mcal/d lost less (P<.01) backfat from parturition through d 14 of lactation, and during the entire lactation period than sows fed 8 Mcal/d

Fluctuations in sow weight and backfat after weaning for primiparous sows fed 8 or 16 Mcal during lactation are reported in table 4. No lactational treatment x postweaning treatment interaction was detected (P>.10) and therefore main effect means were compared. By 14 d after weaning, only sows fed 16 Mcal/d lost (P<.01) weight. Lactational treatment had no (P>.10) effect on weight change from 14 to 28 d after weaning and sows from both lactational treatments gained weight. Primiparous sows fed 8

Mcal/d during lactation tended (P=.08) to gain more weight from weaning to d 28 postweaning than sows fed 16 Mcal/d. Postweaning backfat changes corresponded closely to weight changes. Sows fed 8 Mcal/d during the first lactation deposited more backfat during the first 28 d after weaning (P<.01) than sows previously fed 16 Mcal/d.

Diets during the first lactation influenced weight and backfat gain during the subsequent gestation (table 3). Sows fed 8 Mcal/d during the first lactation gained more (P<.05) weight and backfat during their second gestation than sows fed 16 Mcal/d.

Effects of energy intake during the second lactation on sow backfat and weight changes after weaning are shown in table 5. Only small weight changes occurred during the first 14 d after weaning for second-parity sows fed 8 Mcal/d during lactation. However, sows fed 16 Mcal/d during lactation lost more (P<.01) weight by 14 d after weaning than sows previously fed 8 Mcal/d. Lactational energy had no effect on sow weight change from 14 to 28 d postweaning. Only sows fed 16 Mcal/d during lactation lost (P<.01) weight during the postweaning period. In contrast to the first parity, lactational energy appeared to have little effect on backfat changes after weaning for second-parity sows.

Sows fed 8 Mcal/d during lactation consumed all feed provided during lactation. However, sows assigned to the 16 Mcal/d lactational treatment actually consumed 15.7 Mcal/d. Four percent of sows assigned to 16 Mcal/d during lactation consumed between 12 and 14 Mcal/d. All sows readily consumed thier postweaning diets.

Sow weight and backfat changes during the first and second parity in response to postweaning energy intake are presented in tables 4 and 5. During the initial 14 d after weaning, only sows fed 11.5 Mcal/d maintained their body weight. Primiparous sows fed 5.75 Mcal/d gained less (P<.01) weight and backfat than sows fed 11.5 Mcal/d maintained their body weight. Primiparous sows fed 5.75 Mcal/d gained less (P<.01) weight and backfat than sows fed 11.5 Mcal/d by 14 d postweaning. From 14 to 28 d after weaning primiparous sows fed 11.5 Mcal/d gained more (P<.01) weight and tended (P=.09) to deposit more backfat than sows fed 5.75 Mcal/d. For the entire 28 d postweaning period, primiparous sows fed 11.5 Mcal/d gained more (P<.01) weight and backfat than sows fed 5.75 Mcal/d.

Figure 1 shows the effects of lactational energy intake during the first parity on the concentration of urea in serum. A time by lactational treatment interaction (P=.01) appears to explain higher concentrations of urea at d 14 of lactation and at weaning among sows fed 8 Mcal/d than for sows fed 16 Mcal/d during lactation. Within 14 d after weaning, serum urea for sows fed 8 Mcal/d during lactation had declined while urea concentrations for sows fed 16 Mcal/d during lactation remained low. Only minor changes in urea concentrations were observed 14 to 28 d after weaning regardless of treatment. Throughout the postweaning period, sows fed 5.75 Mcal/d after weaning had higher (P<.01) concentrations of urea compared to sows fed 11.5 Mcal/d. A similar lactation treatment by time interaction (P<.01) for serum urea occured in the second parity (figure 2).

Response of serum creatinine to treatment during the first and second parities is shown in figures 3 and 4, respectively. On d 108 of gestation, primiparous sows fed 8 Mcal/d during lactation had numerically higher concentrations of creatinine. Sows fed 8 Mcal/d had higher (P<.01) concentrations of creatinine during lactation than sows fed 16 Mcal/d. A lactational treatment by postweaning treatment interaction (P<.01) and a tendency for a lactational treatment by time interaction (P=.06) were observed. There was a more marked reduction in serum creatinine on d 14 after weaning for sows fed 8/11.5 Mcal/d (lactation/postweaning) than sows fed 16/11.5. A more pronounced increase in concentrations of creatinine in serum on 14 d after weaning sows fed 16/5.75 Mcal/d vs. sows fed 8/5.75 Mcal also possibly contributed to the interaction between lactational and postweaning treatments. A lactational treatment by time iteraction (P<.01) for serum creatinine was observed for second-parity sows (figure 4). Serum creatinine concentration appeared to be reduced on d 14 postweaning only among sows fed 8 Mcal/d during lactation but increased after weaning in sows fed 16 Mcal/d. Regardless of postweaning treatment, sows fed 16 Mcal/d during lactation had lower (P<.01) concentrations of creatinine in serum.

Litter performance in response to sow energy intake in the first and second lactations is summarized in tables 6 and 7, respectively. Total number of pigs and number of pigs born alive in the first parity tended (P<.07) to be higher for sows that were fed 8 Mcal/d. No treatment differences in pig survival were observed between treatments for the first lactation. Similar results

occurred in the second lactation. Pigs and litters nursing primiparous sows fed 16 Mcal/d were heavier (P<.05) at d 14. In contrast to the first parity, energy intake during the second lactation had little effect on pig or litter weight through the second week of lactation (table 7). However, in both parities sows fed 8 Mcal/d during lactation weaned lighter (P<.05) pigs and litters than sows fed 16 Mcal/d.

Sows fed 8 Mcal/d during the first lactation tended to farrow more (P<.09) live pigs in the second parity than sows fed 16 Mcal/d. Energy intake during the postweaning period had no effect on the total number of pigs, or the number of pigs born alive in the second parity.

The effect of energy intake during the lactation and postweaning periods on the estrous response after weaning is reported in table 8. Neither energy intake during lactation nor after weaning affected return to estrus. However, a trend (P=.16) for a lactation by postweaning treatment interaction for primiparous sows was detected for the frequency of sows exhibiting estrus by 7 d postweaning. This apparent interaction resulted because a lower percentage of sows fed 8/5.75 Mcal/d (lactation/postweaning) returned to estrus by d 7 than when 8/11.5 Mcal/d was fed during lactation. However, increasing postweaning energy intake resulted in a lower percentage of sows in estrus by d 7 postweaning for sows fed 16 Mcal/d during lactation. Slightly fewer (75.0 vs 86.8%) sows that had been fed 16 Mcal/d during lactation farrowed a second litter, but no treatment differences for farrowing rate at the second parity were observed.

Only three sows (one fed 16/11.5 Mcal/d, one fed 16/5.75 Mcal/d and one sow fed 8/11.5 Mcal daily) ovulated without detected estrus as indicated by corpora lutea at slaughter.

Discussion

Sow weight and backfat loss was influenced markedly by lactational energy intake during both the first and second lactation. This experiment was not designed to compare parities. However, it appeared that first-parity sows lost less weight and more backfat than second-parity sows. Reasons for an apparent difference in tissues catabolized between parities is unknown, but could result from increased maintenance requirements for second-parity sows. Increased loss of weight during lactation has been reported to result from restriction of feed intake (Lodge, 1959; Elsley et al., 1969; King and Williams, 1984a), protein intake (Greenhalgh et al., 1977; DeGeeter et al., 1972; O'Grady et al., 1975b), energy intake (O'Grady et al., 1975a; Reese et al., 1982a, 1984; Elsley et al., 1968; Nelssen et al., 1985a), or changes in energy source (Nelssen et al., 1985b) during lactation. Therefore, loss of weight and backfat during first or second lactation can be reduced by feeding more energy.

Sow weight changes after lactational energy restriction in the present study produced results similar to protein restriction during lactation (King and Williams, 1984b). King and Williams (1984b) demonstrated that increasing protein intake (approximately 310 vs 650 g/d) markedly reduced weight loss, but had little effect on backfat loss when sows were fed a high energy diet

(16.6 Mcal DE/d). In contrast, sows fed a low energy diet lost substantial weight and backfat, but loss of backfat was more pronounced among sows fed high protein diets. Thus an interaction between energy and protein intake for weight loss occurred. Further evidence to support a nutritional relationship between energy and protein intake was presented by Brendemuhl (1985) who observed that sows restricted in either energy (8 Mcal/d) or protein (380 g/d) lost more weight during lactation than sows fed high protein (760 g/d) or energy (16 Mcal/d). Brendemuhl (1985) also found that sow weight loss decreased in response to energy to a greater extent when protein was high. However, backfat loss was increased after energy restriction and low energy, high protein diets tended to increase backfat loss. Brendemuhl (1985) concluded that tissue catabolism during lactation occurred as a result of both energy and protein restriction, but suggested that despite similarities in lactational weight loss between sows fed high energy/low protein and those fed low energy/high protein during lactation, composition of the loss may be different. Because sows in the current study (8 Mcal/d) were restricted only in energy, it is likely they preferentially mobilized backfat.

Effects of lactational energy intake may have persisted in the postweaning period. Regardless of lactational energy intake, by 28 d postweaning sows had not regained their postfarrowing weight. However, sows fed 16 Mcal/d during lactation lost substantially more weight during the first 14 d after weaning (tables 4 and 5). High lactational intake of energy may alter

the metabolism of sows such that the efficiency of energy utilization is reduced, resulting in increased weight loss after weaning. Another possibility is that high lactational energy intake is accompanied by an increase in water retention in mammary tissue during lactation and sows fed 16 Mcal/d may have lost more weight after weaning because of greater depletion of body water. That body water accounts for a portion of the weight loss after weaning is suggested by slight increases in backfat depth within 14 d after weaning despite weight loss by first and second-parity sows fed 16 Mcal/d during lactation. Increased gestation weight gain of second-parity sows fed 8 Mcal/d during the first lactation (table 3) lends further support to the hypothesis that sow maintenance requirements are reduced as a result of less weight and backfat at weaning, and therefore more of the gestation diet was available for sow and fetal growth. In agreement with our results, Reese et al. (1982b) reported a compensatory gain during gestation following a restricted lactational energy intake. During the initial 14 d after weaning, only sows fed 11.5 Mcal/d from weaning to estrus maintained their body weight (tables 4 and 5). Our results demonstrate that feeding 11.5 Mcal/d after weaning substantially reduces or prevents weight losses during the immediate postweaning period. Backfat changes responded to postweaning treatment after the first lactation (table 4), but not after the second lactation (table 5). This parity difference may have resulted from a shorter postweaning interval to estrus for second parity sows. A similar explanation may hold for sow weight changes as affected by

postweaning treatments and parity because essentially all second-parity sows were fed the gestation diet by 14 d after weaning.

Based on concentrations of urea in serum, first and second-parity sows fed 8 Mcal/d during lactation appeared to catabolize more protein on d 14 and 21 of lactation than sows fed 16 Mcal/d. Apparently, protein catabolism was substantially reduced after weaning regardless of energy intake during lactation. Among sows fed 11.5 Mcal/d after weaning, protein catabolism remained slightly lower at 28 d after weaning. Therefore, sows fed 8 Mcal/d during lactation were catabolizing considerable protein. Concentrations of creatinine in serum indicate sows fed 8 Mcal/d during lactation catabolized more tissue protein while lactating than sows fed 16 Mcal/d. However, the difference between creatinine concentration at the onset of the first lactation leaves a degree of doubt whether the entire treatment difference was due to treatment or partially explained by differences between animals prior to treatment. On the basis of first parity results, our data suggests that catabolism of sow tissue protein on d 14 after weaning was reduced by feeding 11.5 Mcal/d from weaning to first estrus.

All sows had a considerable degree of tissue catabolism at the completion of the second gestation as indicated by serum creatinine (figure 4). However, lactational energy intake had a similar effect on serum creatinine to that observed for the first lactation. Our data suggest that endogenous protein catabolism during lactation can be reduced by feeding 16 Mcal/d and that a substantial amount of the increased weight loss for sows fed 8 vs

16 Mcal/d during lactation was due to catabolism of tissue protein.

Litter size in primiparous sows appeared to be influenced by lactational treatment (table 6), however this must be due to chance because treatments were not imposed until after parturition. The tendency for second-parity sows fed 8 Mcal/d during lactation to farrow larger litters may have been a carry-over effect from the first lactation. The total number of pigs born in the first parity was used as a covariate to test lactational treatment effects on second litter size. The covariate was not useful in explaining variation in the second littersize. Therefore second litter size may have been affected by first lactational energy intake. Our data tend to agree with the results of O'Grady et al. (1973) who reported a linear decrease in second-parity litter size with increasing energy intake during the first lactation. Pig survival was unaffected by energy intake during lactation in either parity (tables 6 and 7). Pig survival was high and treatment effects may have been more likely had pig survival been lower.

Pig and litter weights responded to increased lactational energy intake (tables 6 and 7). National Research Council (1979) recommendations of 618 g crude protein/d for a medium producing sow were met or exceeded in our study. Sows fed 16 Mcal/d during lactation weaned heavier litters. This may have resulted from increased milk production and(or) changes in milk composition. Research does not suggest dramatic changes in milk composition as a result of energy addition to the lactational diet (O'Grady et

al., 1973). Therefore, it appears that increasd milk production is the likely factor responsible for increased litter weaning weight for sows fed 16 Mcal/d in the present study. Our research indicates that when sows are fed National Research Council (1979) recommendations for protein, dietary energy can limit milk production.

Results further suggest that energy is an avenue to control milk production when adequate protein is supplied. One possible consideration is that increasing energy intake while providing adequate protein could result potentially in increased output of all nutrients to maintain milk production. This could theoretically place an increased demand on the sow's tissue and skeletal reserves for protein and(or) other nutrients.

Little or no effects of either lactational or postweaning energy intake on interval to estrus are apparent in this study. These results contradict those reported by (Reese et al., 1982a,b, 1984; Nelssen et al., 1985a,b; Brendemuhl, 1985). Differences between this study and those cited above are lactation length (28 vs 21 d in the present study) and sow breed (Large White x Landrace x Duroc vs Duroc x Yorkshire in the present study). Sows fed 16 Mcal/d during lactation in the current study lost substantial weight during lactation. In contrast, studies demonstrating a shorter interval to estrus after feeding 16 Mcal/d during lactation reported minimal lactational weight loss. An explanation for the inability of 16 Mcal/d to prevent lactational weight loss in the present study is not apparent. However, failure of 16 Mcal/d to prevent weight loss may explain why interval to

estrus did not respond to increased lactational energy intake in the present study.

Conclusion

These data support the results of Reese et al. (1982a), Reese et al. (1984) and Nelssen et al. (1985a) who have demonstrated that sows restricted in energy intake during lactation lose considerable weight and backfat while lactating. They further support reports by Nelssen et al. (1985a) and Brendemuhl et al. (1985) that sows restricted in energy intake during lactation catabolize more protein than those fed more liberally. In contrast to the results of Nelssen et al. (1985a), our results indicate that during lactation a significant portion of the protein catabolized by energy restricted sows appears to be of endogenous origin. In contrast to results cited by Reese et al. (1982a), Reese et al. (1982b) and Reese et al. (1984), restriction of energy intake during the first or second lactation did not appear to inhibit an early return to estrus. Additional energy after weaning appeared to reduce postweaning weight loss but had little influence on reproduction. In spite of the fact that sows lost more weight in the second parity than in the first, the majority returned to estrus within one week after weaning. Increasing energy intake during lactation when all other requirements of the sow are met has a positive influence on pig weaning weights. This influence appears to result from a stimulatory effect of energy on milk production. Thus these results suggest that restriction of energy intake to first parity sows dramatically reduces the ability of the

sow to maintain body weight and subcutanious fat reserves during lactation, increases catabolism of protein from both endogenous and dietary sources during lactation, increases weight and backfat deposition after weaning and throughout the subsequent gestation but has little or no major effect on reproduction.

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TABLE 1. COMPOSITION OF GESTATION, LACTATION AND POSTWEANING DIETS (G/D)

Ingredient	Gestation[a]	Lactation[b] 8	Lactation[b] 16	Postweaning[c] 5.75	Postweaning[c] 11.5
Corn		568	568	341	341
Sorghum, grain	1465				
Soybean meal	273	1314	1295	436	422
Wheat starch		57	1755	491	1671
Dried fat[d]		214	427	173	341
Tallow, bleachable fancy[d]		57	114	45	91
Limestone	20	39.5	39.5	11	11
Dicalcium phosphate	40	107	107	52	52
Salt	9	23	23	9	9
Vitamin mix[e]	5	23	23	4.5	4.5
Trace mineral mix[f]	2	4.5	4.5	2	2

[a] The gestation diet was fed until d 108 of gestation and provided the following amounts (g/d) of crude protein, Ca, and P: 251, 16, and 14.3, respectively and 5.6 Mcal of $ME \cdot sow^{-1} \cdot d^{-1}$.

[b] The lactation diets provided the following amounts (g/d) of crude protein, Ca, and P: 636, 41, and 32, respectively.

[c] Postweaned diets provided crude protein, Ca, and P in the following amounts (g/d): 227, 16, and 14.5, respectively.

[d] Fat provided 24.0 and 24.4% of daily energy intake for lactation and postweaning diets, respectively.

[e] Each kg of premix contained: vitamin A, 1,760,000 IU; vitamin D_3, 132,000 IU; riboflavin, 1980 mg; choline, 202.8 g; d-pantothenic acid, 5280 mg; niacin, 11,000 mg; vitamin E, 8800 IU; vitamin B_{12}, 9.7 mg; menadione dimethylpyrimidinal bisulfite, 682 mg; ethoxyquinone, 6270 mg.

[f] Percentage composition was: Mn, 12; Fe, 10; Cu, 1.0; Zn, 15; I, .3; Co, .1.

TABLE 2. SOW BACKFAT AND WEIGHT CHANGES DURING THE FIRST GESTATION AND LACTATION[a,b]

	Metabolizable energy (Mcal/d)						
	Lactation						
	8		16		8	16	
Item	Weaning to estrus 5.75	11.5	5.75	11.5	Combined	Combined	CV [c], %
No. of sows	26	26	26	26	52	52	
Prefarrowing wt,[de] kg	178.6	177.4	179.0	179.5	178.0	179.3	3.5
Prefarrowing backfat,[e] mm					26.3	26.6	
Postfarrowing wt,[d] kg					164.1	164.8	
Weight change,[d] kg							
Gestation	64.8	64.7	65.3	65.1	64.8	65.2	10.2
Lactation							
1 to 14 d[f]	-13.8	-13.4	-5.1	-4.8	-13.6	-5.0	51.5
14 to 21 d[f]	-8.2	-8.3	-4.4	-5.5	-8.3	-5.0	71.8
1 to 21 d[f]	-22.0	-21.7	-9.5	-10.3	-21.8	-9.9	37.1
Backfat change,[d] mm							
Gestation	2.9	2.9	3.1	2.7	2.9	2.9	68.0
Lactation							
1 to 14 d[f]	-4.3	-4.9	-1.6	-2.6	-4.6	-2.1	50.3
14 to 21 d[f]	-4.0	-3.8	-2.0	-1.6	-3.9	-1.8	63.5
1 to 21 d[f]	-8.3	-8.7	-3.6	-4.2	-8.5	-3.9	30.6

[a] Models included replicate, actual age of pigs at 2 and 3 wk weights, pigs nursed, backfat on d 108 gestation, and sow weight after farrowing.

[b] No lactation x postweaning treatment interaction was detected for sow weight or backfat changes (P>.49).

[c] Coefficient of variation = 100 SD/$\bar{X}$.

[d] Least-squares means.

[e] Day 108 of gestation.

[f] Lactational treatment means differ (P<.05).

TABLE 3. SOW BACKFAT AND WEIGHT CHANGES DURING THE SECOND GESTATION AND LACTATION[a]

	Metabolizable energy (Mcal/d)						
	8		16		Combined		
Item — Lactation Weaning to estrus	5.75	11.5	5.75	11.5	8	16	CV, %[b]
No. of sows	20	18	17	17	38	34	
Prefarrowing wt,[c,d] kg	193.7	195.5	201.2	204.4	194.6	202.7	6.5
Prefarrowing backfat,[d] mm	25.5	23.8	26.9	25.9	24.7	26.4	13.1
Postfarrowing wt,[c] kg	179.5	183.0	193.6	188.4	181.3	191.0	6.8
Weight change, kg							
Gestation[d]	52.2	52.4	44.4	49.7	52.3	47.1	19.1
Lactation							
1 to 14 d[d]	-14.7	-15.1	-6.9	0.0	-14.9	-3.5	85.2
14 to 21 d[e]	-11.5	-9.5	-7.0	-9.0	-10.5	-8.0	37.6
1 to 21 d[d]	-26.7	-24.7	-14.0	-8.9	-25.7	-11.5	43.9
Backfat change, mm[c]							
Gestation[d]	7.6	6.1	4.5	4.0	6.9	4.3	43.5
Lactation							
1 to 14 d[d]	-5.1	-3.5	-2.0	-1.8	-4.3	-1.9	75.2
14 to 21 d[d]	-2.0	-1.9	-1.5	-0.3	-1.9	-0.9	185.0
1 to 21 d[d,f]	-7.1	-5.4	-3.5	-2.1	-6.2	-2.8	65.5

[a] Models included replicate, actual age of pigs at 2 and 3 wk weights and pigs nursed.
[b] Coefficient of variation = 100 SD/$\bar{X}$.
[c] Least-square means.
[d] Lactation treatment differ (P<.05).
[e] A lactational × postweaning treatment interaction was detected (P=.02).
[f] Postweaning treatment means differ (P<.05).

TABLE 4. SOW BACKFAT AND WEIGHT CHANGES AFTER WEANING AS AFFECTED BY DIETARY ENERGY DURING THE FIRST LACTATION AND FOLLOWING WEANING[a,b]

Item	Lactation Weaning to estrus								CV,%[c]
	Metabolizable energy (Mcal/d)								
	8		16		8	16	Combined		
	5.75	11.5	5.75	11.5	Combined	Combined	5.75	11.5	
No. of sows	26	26	26	26	52	52	52	52	
Weight at weaning, kg[d,e,f]	142.4	142.7	154.8	154.1	142.6	154.5	148.6	148.4	4.0
Postweaning weight change, kg									
0 to 14 d[e,f]	-1.1	1.5	-4.0	-.7	.2	-2.4	-2.6	.4	336.1
14 to 28 d[f]	2.1	4.7	3.1	4.9	3.4	4.0	2.6	4.8	96.4
0 to 28 d	1.0	5.9	-.9	4.2	3.5	1.6	.1	5.0	203.1
Backfat at weaning, mm[d,e]	18.1	17.7	22.8	22.3	17.9	22.5	20.4	20.0	9.5
Postweaning backfat change, mm									
0 to 14 d[e,f]	.9	2.4	.0	.8	1.6	.4	.5	1.6	167.7
14 to 28 d[e]	1.1	2.2	.7	.9	1.7	.8	.9	1.6	154.7
0 to 28 d[e,f]	2.0	4.5	.7	1.8	3.2	1.3	1.4	3.1	101.9

[a]Models included replicate, actual age of pigs at 2 and 3 wk weights, pigs nursed, backfat on d 108 of gestation and sow weight after farrowing.
[b]No lactation x postweaning treatment interaction was detected for sow weight or backfat changes (P>.18).
[c]Coefficient of variation = 100 SD/X̄.
[d]Least-squares means.
[e]Lactational treatment means differ (P<.05).
[f]Postweaning treatment means differ (P<.05).

TABLE 5. SOW BACKFAT AND WEIGHT CHANGES AFTER WEANING AS AFFECTED BY DIETARY ENERGY DURING THE SECOND LACTATION AND FOLLOWING WEANING[a,b]

Item	Lactation Weaning to estrus	Metabolizable energy (Mcal/d)								CV,[c] %
		8		16		8	16	Combined		
		5.75	11.5	5.75	11.5	Combined	Combined	5.75	11.5	
No. of sows		20	18	17	17	38	34	37	35	
Weight at weaning,[de] kg		153.9	158.6	179.9	179.3	156.2	179.6	166.9	169.0	8.0
Postweaning weight change,[d] kg										
0 to 14 d[def]		-1.7	1.6	-5.1	-1.5	-.1	-3.3	-3.4	.1	303.0
14 to 28 d[f]		1.9	-1.6	.4	.1	.2	.2	1.1	-.8	3517.2
0 to 28 d[e]		.1	0.0	-4.7	-1.4	.1	-3.1	-2.3	-.7	300.6
Backfat at weaning,[de] mm		18.4	18.5	23.4	23.8	18.4	23.6	20.9	21.1	19.7
Postweaning backfat change,[d] mm										
0 to 14 d		.3	1.0	.9	.3	.7	.6	.6	.7	340.0
14 to 28 d		.2	0.0	-.6	-.5	.1	-.6	-.2	-.3	998.1
0 to 28 d		.4	1.0	.3	-.3	.7	0.0	.4	.4	470.4

[a] Models included replicate, actual age of pigs at 2 and 3 wk weights and pigs nursed.
[b] No lactation x postweaning treatment interaction was detected for sow weight or backfat changes (P>.09).
[c] Coefficient of variation = 100 SD/X̄.
[d] Least-squares means.
[e] Lactational treatment means differ (P<.05).
[f] Postweaning treatment means differ (P<.05).

TABLE 6. LITTER PERFORMANCE AS AFFECTED BY DIETARY ENERGY DURING THE FIRST LACTATION[a,b]

Item	Lactation Weaning to estrus	Metabolizable energy (Mcal/d)						CV,[c] %
		8		16		8	16	
		5.75	11.5	5.75	11.5	Combined	Combined	
No. of sows		20	18	17	17	52	52	
Number of pigs								
Total born[b]		10.2	9.7	9.1	9.4	10.0	9.2	21.2
Born alive[d]		9.8	9.2	8.6	8.9	9.5	8.8	22.0
14 d		8.9	9.0	8.9	8.9	8.9	8.9	5.7
21 d		8.9	8.8	8.8	8.7	8.8	8.8	7.5
Pig survival,[d] %								
1 to 14 d		96.2	97.1	97.1	96.8	96.6	96.6	5.4
1 to 21 d		95.8	95.8	96.0	94.7	95.8	95.3	7.2
Pig wt.,[d] kg								
14 d[e]		3.7	3.7	3.8	4.0	3.7	3.9	11.8
21 d[e]		5.1	5.0	5.5	5.5	5.1	5.5	11.5
Litter wt.,[d] kg								
14 d[e]		33.1	33.1	34.3	35.6	33.1	34.9	12.9
21 d[e]		44.7	44.0	48.5	47.7	44.3	48.1	13.6

[a] Models included replicate, actual age of pigs at 2 and 3 wk weights, pigs nursed, backfat on d 108 of gestation, and sow weight after farrowing.
[b] No lactation x postweaning treatment interaction was detected for pig survival and pig or litter weight (P>.34).
[c] Coefficient of variation = 100 SD/X̄.
[d] Least-squares means.
[e] Lactational treatment means differ (P<.05).

TABLE 7. LITTER PERFORMANCE AS AFFECTED BY DIETARY ENERGY DURING THE SECOND LACTATION[a,b]

Item		Metabolizable energy (Mcal/d)						CV, %[c]
	Lactation Weaning to estrus	8		16		8	16	
		5.75	11.5	5.75	11.5	Combined	Combined	
No. of sows	20	18	17	17	38	34		
Number of pigs								
Total born[d]	10.8	9.0	8.5	8.8	10.1	8.4	30.7	
Born alive[d]	9.8	7.9	8.4	8.1	9.1	8.0	30.6	
14 d	8.6	8.5	8.3	8.2	8.5	8.3	7.4	
21 d	8.5	8.2	8.2	8.2	8.4	8.2	8.8	
Pig survival,[d] %								
1 to 14 d	98.0	97.4	95.9	94.3	97.7	95.1	6.8	
1 to 21 d	97.7	93.7	95.3	94.4	95.7	94.9	8.5	
Pig wt.,[d] kg								
14 d	3.9	4.0	4.2	4.0	4.0	4.1	14.1	
21 d[e]	5.5	5.8	6.4	6.0	5.7	6.2	12.6	
Litter wt., kg								
14 d	32.7	34.0	34.7	32.8	33.3	33.8	15.0	
21 d[e]	46.3	46.4	52.0	49.1	46.4	50.5	14.4	

[a] Models included replicate, actual age of pigs at 2 and 3 wk weights and pigs nursed.
[b] No lactation x postweaning treatment interaction was detected for pig survival and pig or litter weight (P>.10).
[c] Coefficient of variation = 100 SD/$\bar{X}$.
[d] Least-squares means.
[e] Lactational treatment means differ (P<.05).

TABLE 8. LACTATION BY POSTWEANING TREATMENT EFFECTS OF DIETARY ENERGY INTAKE ON PERCENTAGE OF SOWS IN ESTRUS POSTWEANING

	Metabolizable energy intake (Mcal/d)							
	Parity 1				Parity 2			
		Lactation/Postweaning[a]				Lactation/Postweaning[a]		
Item	8/5.75	8/11.5	16/5.75	16/11.5	8/5.75	8/11.5	16/5.75	16/11.5
Number of sows	26	26	26	26	20	18	17	17
Percent of sows in estrus by (d after weaning):								
7	46.2	57.7	69.2	53.8	85.0	94.4	88.2	94.1
14	73.1	76.9	80.8	73.1	95.0	100.0	100.0	100.0
21	80.8	84.6	84.6	80.8	95.0	100.0	100.0	100.0
28	92.3	92.3	88.5	96.2	100.0	100.0	100.0	100.0

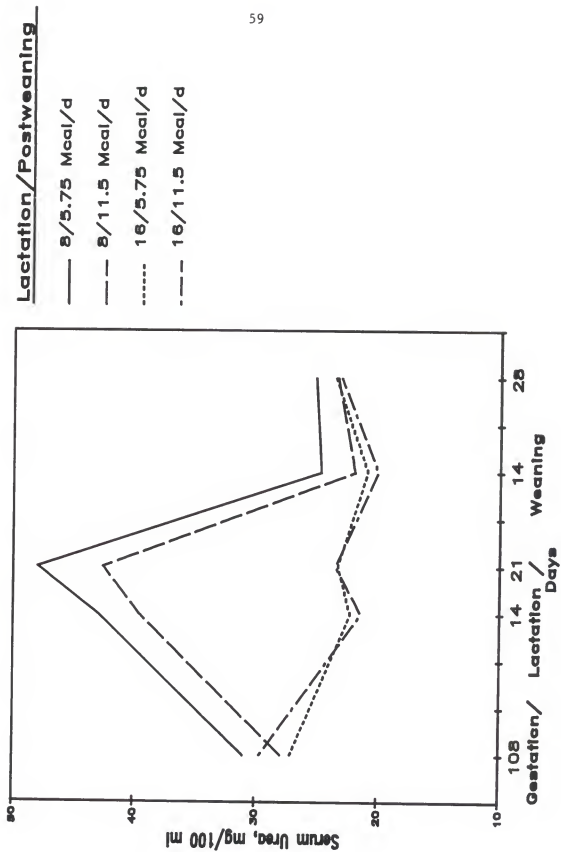[a]Postweaning energy treatments were fed from weaning until detection at first estrus.

CATALOG OF FIGURES

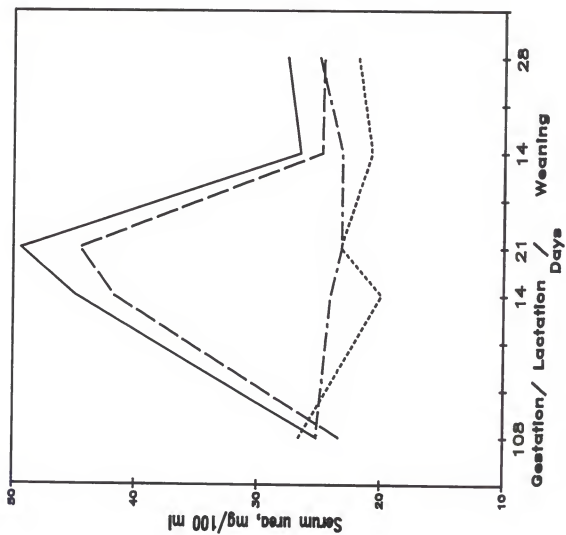Figure 1. Concentrations of urea in serum as affected by energy intake of first parity sows during lactation and after weaning. Sow diets provided 8 or 16 Mcal/d during lactation and 5.75 or 11.5 Mcal/d from weaning to estrus. Effects of lactational and postweaning treatments, and time, $P < .05$. Lactation x postweaning treatment and lactation treatment x time, $P < .05$.

Figure 2. Concentrations of urea in serum as affected by energy intake of second parity sows during lactation and after weaning. Sow diets provided 8 or 16 Mcal/d during lactation and 5.75 or 11.5 Mcal/d from weaning to estrus. Effects of lactational and postweaning treatments, and time, $P < .05$. Lactation x postweaning treatment and lactational treatment x time, $P < .001$.
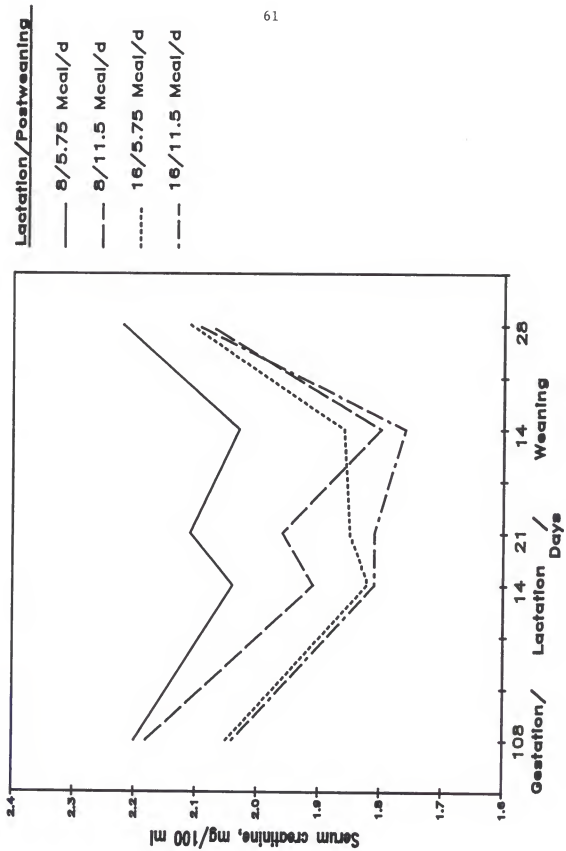
Figure 3. Concentrations of creatinine in serum as affected by energy intake of first parity sows during lactation and after weaning. Diets provided 8 or 16 Mcal/d during lactation and 5.75 or 11.5 Mcal/d from weaning to estrus. Effects of lactational and postweaning treatments, and time, $P < .001$. Lactation x postweaning treatment, $P < .01$.
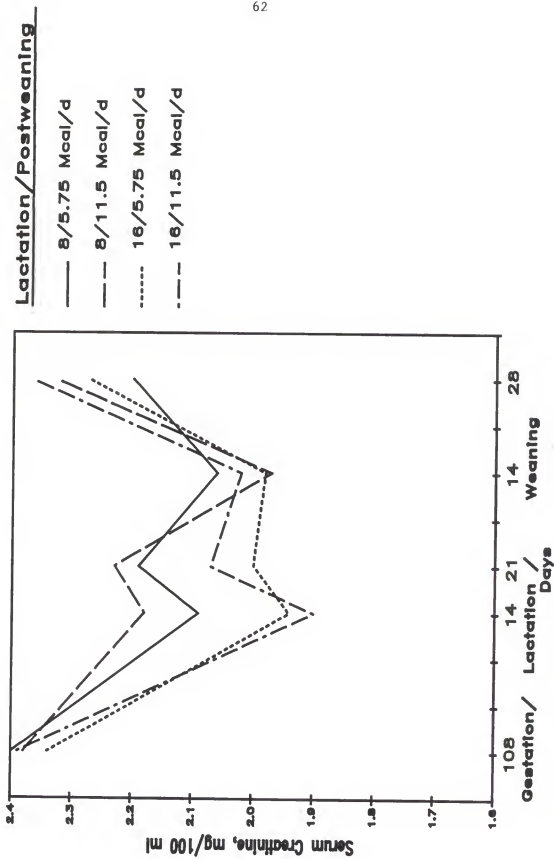
Figure 4. Concentrations of creatinine in serum as affected by energy intake of second parity sows during lactation and after weaning. Diets provided 8 or 16 Mcal/d during lactation and 5.75 or 11.5 Mcal/d from weaning to estrus. Effects of lactational treatments, lactation x postweaning treatment, and time, $P < .001$. Lactation treatment x time, $P < .001$. No postweaning treatment effects were observed, $P > .36$.

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Lactation/Postweaning

—— 8/5.75 Mcal/d

– – 8/11.5 Mcal/d

····· 16/5.75 Mcal/d

–·– 16/11.5 Mcal/d

Serum creatinine, mg/100 ml

Lactation/Postweaning
——— 8/5.75 Mcal/d
— — 8/11.5 Mcal/d
········ 16/5.75 Mcal/d
—·—· 16/11.5 Mcal/d

INFLUENCE OF DIETARY ENERGY INTAKE DURING LACTATION AND
FOLLOWING WEANING ON SOW AND LITTER PERFORMANCE

by

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B.S., Panhandle State University, 1982

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AN ABSTRACT OF A MASTER'S THESIS

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Four replications of a split plot experiment were conducted using a total of 104 crossbred sows to evaluate the effects of two energy intakes on sow reproductive performance during lactation (21 d) and another two energy intakes from weaning to estrus. Criteria of response were: changes in sow body tissues, litter performance, and sow reproductive performance. Urea and creatinine in serum of sows also were measured. At parturition, primiparous sows were assigned randomly to one of two lactation treatments: either 8 or 16 Mcal metabolizable energy (ME) sow^{-1} d^{-1}. Pigs were not creep fed during lactation but had access to sow feed. Postweaning treatments consisted of two energy intakes: 5.75 or 11.5 Mcal of ME sow^{-1} d^{-1}. Sows were checked for estrus twice daily after weaning in the presence of a boar until detected inestrus or 30 d.

There were no interactions between lactational and postweaning treatments for sow weight and backfat changes, litter performance, and reproduction (P>.05) in the first parity. Similar effects were generally observed in the second parity. First and second–parity sows fed 16 Mcal/d during lactation lost less (P<.001) weight and backfat during lactation and weaned heavier (P<.05) litters than sows fed 8 Mcal/d. Primiparous sows fed 5.75 Mcal/d after weaning lost more (P<.01) weight and gained less backfat within 14 d after weaning and subsequently lost more (P<.05) backfat during the second lactation than sows fed 11.5 Mcal ME/d. Sows fed 16 Mcal/d during lactation had lower (P<.05) concentrations of urea in serum at weaning than sows fed 8 Mcal/d. Pig survival to weaning was unaffected by maternal

energy intake during the first two parities. Regardless of parity, sows fed 16 Mcal/d during lactation had more (P<.05) backfat and were heavier (P<.001) at weaning than sows fed 8 Mcal/d. However, during the initial 14 d after weaning, sows fed 16 Mcal/d during lactation lost more (P<.002) weight and in the first parity replenished less (P<.002) backfat. Intake of energy during lactation or following weaning had no effect on farrowing rate or the percentage of sows returning to estrus after weaning the second litter. Primiparous sows fed 8 Mcal/d during lactation tended (P<.08) to farrow more (10.1 vs 8.4, respectively) pigs at the second parity than sows fed 16 Mcal/d. These results indicate that 16 Mcal/d for first or second parity lactating sows increased preweaning litter gain and pig weaning weight and reduced immediate sow weight and backfat loss, but had no major effects on sow reproduction.

Key Words: (Primiparous Sows, Energy Intake, Lactation, Postweaning, Estrus, Reproduction.)